INFORMATION TECHNOLOGY SUPPORT TO IMPROVED CONSTRUCTION PROCESSES: INTER-DISCIPLINARITY IN RESEARCH AND PRACTICE

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ABSTRACT

Research and innovation in the built environment is increasingly taking on an inter-disciplinary nature. The built environment industry and professional practice have long adopted multi and inter-disciplinary practices. The application of IT in Construction is moving beyond the automation and replication of discrete mono and multi-disciplinary tasks to replicate and model the improved inter-disciplinary processes of modern design and construction practice. A major long-term research project underway at the University of Salford seeks to develop IT modelling capability to support the design of buildings and facilities that are buildable, maintainable, operable, sustainable, accessible, and have properties of acoustic, thermal and business support performance that are of a high standard. Such an IT modelling tool has been the dream of the research community for a long time. Recent advances in technology are beginning to make such a modelling tool feasible.

Some of the key problems with its further research and development, and with its ultimate implementation, will be the challenges of multiple research and built environment stakeholders sharing a common vision, language and sense of trust. This paper explores these challenges as a set of research issues that underpin the development of appropriate technology to support realisable advances in construction process improvements.

KEYWORDS
Construction process improvement; inter-disciplinarity; multi-disciplinarity; construction IT; nD modelling; trust; multi-criteria decision making.

INTRODUCTION

The building design process is complex encapsulating a great number and variety of factors - which can be social, economic and legislative - in order to satisfy the client's requirements. In fact, it is rarely the case that there will be one homogeneous client, but a number and variety of stakeholders who will be the end users of the design and its resultant product. These can include, not only the organisations and individuals who will occupy the building on a daily basis, but also those who provide it, manage it, own it, maintain it and be affected by it by its existence in their environment**.**

Project Context

There are increasing demands being made by multiple stakeholders for inclusion of design features such as buildability (cost and time), maintainability, sustainability, accessibility, crime deterrence and acoustic and energy performance. This diversity in stakeholder aspiration arises from increasing numbers of construction specialists who may now be involved in design. Each design parameter that these stakeholders seek to consider will have a host of social, economic and legislative constraints which often are in conflict with one another. The criteria for successful design therefore will include a measure of the extent to which all these factors can be co-ordinated and mutually satisfied to meet the expectations of all the parties involved. In this era of increasing global competition, being able to deliver value to clients - and integrated design, if this is what the market dictates - is what could set one company ahead of the competition.

The volume of information required by so many experts make it difficult for the client to visualise design changes and their impacts upon the time and cost of the project. Design adaptations which aid a client's decision-making ability in this way are also costly, time consuming and laborious. A multi-dimensional computer model, which allows the entire design and construction process to be portrayed visually, would enhance both the decision-making and construction processes, by enabling true and holistic 'what-if' analyses to be performed. This is the ultimate aim of the 3D to nD modelling research project underway at the University of Salford. Conceptually, this will involve taking 3-dimensional modelling in the built environment to an *n* number of dimensions[1].

The research seeks to develop the infrastructure, methodologies and technologies that will facilitate the integration of time, cost, buildability, accessibility, sustainability, maintainability, acoustics, crime, lighting and thermal requirements. It aims to assemble and combine the leading advances that have been made in discrete information communication technologies (ICTs) and process improvement to produce an integrated prototyping platform for the construction and engineering industries. This output will allow seamless communication, simulation and visualisation, and intelligent and dynamic interaction of emerging building design prototypes, so that their fitness for purpose for economic, environmental, building performance, and human usability will be considered in an integrated manner. It is essential to ensure that the proposed system would be durable and be compatible with new developments in IT, a far as these could be anticipated.

Project Aims and Structure

The Engineering and Physical Sciences Research Council (EPSRC) in the UK fund the 3D2nD project as a platform grant. Platform grants are a recent innovation in UK government research

[1] The term *nD modelling* was coined in Barrett (2000)

funding and are intended to allow longer time-scale and more fundamental basic research within leading national centres of excellence of an internationally-leading standing, into strategic research of global importance. Salford University has secured one of the first of these grants within the Built Environment on the back of its well-established research in IT, management and environmental and design systems. The project has a large pool of senior academics from multiple disciplines within its project team. It was agreed by the project members that the nD tool should encompass people, technology, process (organisation of work), organisational relevance (business strategy/market positioning) and the business model (cost effective, capable of being developed) issues. This has led to the emergence of 5 work packages, whose interrelationships are illustrated by figure 1.

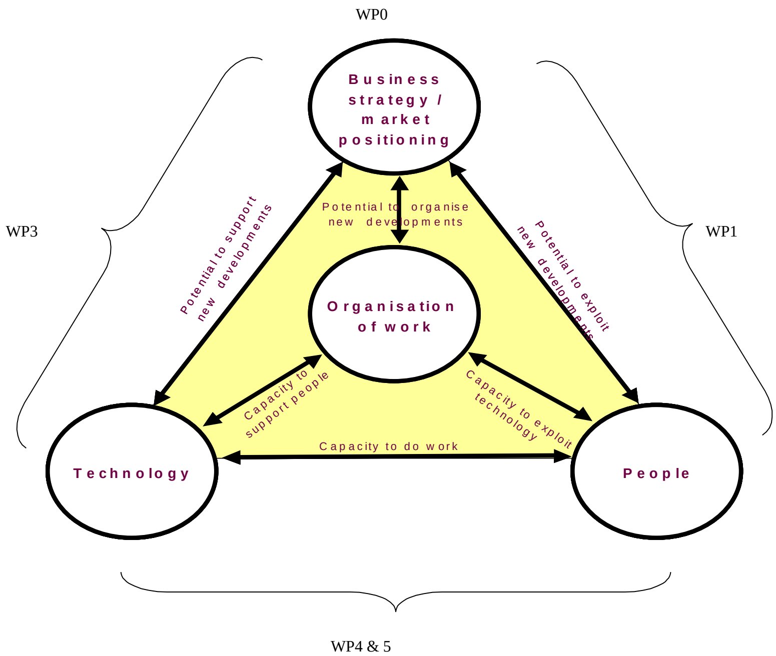

Figure 1: Work packages of the 3D2nD project[2]

The Focus of this Paper

In view of the number and diversity of project researchers representing the requirements of construction industry stakeholders and professionals, it can be expected that gaining consensus on the characteristics of a vision for the project will be problematic and require management. Each work package inherently embodies different epistemological approaches, for example WP3's model testing will be objective and likely empirical in nature, whereas WP4's technology transfer will be more qualitative in nature and concerned with the organisational and social features and processes which will aid or inhibit the technology implementation. Should consensus be achieved and if lacking, how should it be handled so as to not jeopardise the projects' overall deliverables? This has been a key challenge for the research team in the project and is indicative of the issues associated with resolving conflicting perspectives and requirements of multiple stakeholders that the model itself will be called on to perform. As a means of exploring these trade-offs and multi-criteria maximisation issues, this early paper from the research explores how research teams might resolve these differences in approach within their own research methodology and management. Two earlier examples of multi-disciplinary research projects are examined as case studies to surface the associated risks and issues and provide some guidelines for effective inter-disciplinary research

[2] Barrett & Sexton (2001)

working on which this project can draw. It is argued that such inter-disciplinary approaches will increasingly become key to our broader advances in building and construction technology research and innovation.

CASE STUDY 1: AN INTERDISCIPLINARY EU-FUNDED RESEARCH NETWORK

Cooper (2002) uses the BEQUEST network, an EU concerted action with 14 partners from 6 countries, as an example of a major research exercise that illustrates the problems of multi-disciplinary working. The network's aim was to bridge discipline-based differences held by those working in the urban sustainability field to develop a shared platform for assessing sustainable urban development (SUD). This objective necessitated consensus building between the project's immediate partners, but also within the wider built environment community through its Extranet. It is of relevance to the nD modelling project because of its varied stakeholders working in the built environment field. Cooper argues (p117) that BEQUEST faced a triple challenge, because:

(1) There is no consensus of the meaning of SUD (Palmer et al 1997) or how it should be implemented;
(2) There is no agreement and little advice (Epton et al 1983) on how interdisciplinary research should be conducted, despite expressed needs to support this activity in the UK (e.g. HEFCE 2001);
(3) There is little shared experience on how to design and run effective virtual organisations, despite the rapid recognition of their appearance after the rise of the Internet

Multi- vs. Inter-disciplinary working

Cooper distinguishes between 'multi-disciplinary and 'inter-disciplinary' working (p118). The former term applies when two or more disciplines work together without stepping outside their own traditional discipline boundaries. In contrast, the latter emphasises the development of a shared perspective transcending traditional boundaries. Newell and Swan (2000) use the analogies of jigsaws and kaleidoscopes: in multi-disciplinary work, the individual pieces of the jigsaw do not change their identities as a result of being combined with other pieces, whilst with the inter-disciplinary kaleidoscope, it is not possible to establish characteristics of each individual from the whole. BEQUEST is an example of the latter as the emergent conceptual frameworks the members created transcended those owned by any one discipline making up that group (p121).

Examining and building consensus

Cooper draws attention to the 'wheel of cognate disciplines' (Eclipse Research Consultants 1997) which suggests that the closer disciplines are located to each other, the more likely they are to share a common theoretical parentage and therefore the more open their boundaries are to each other. In BEQUEST's case, the most common partner disciplines - engineering, planning and architecture - formed an arc and so it could be expected that collaboration would be fairly straightforward. However, this was not the case and Cooper argues this might be partially explained by the situated nature of professional learning and expertise: "'Legitimate peripheral participation' provides a way to speak about the relations between newcomers and old-timers and concerns the process by which newcomers become part of a community of practice" (Lave and Wenger, 1991). In BEQUEST's case, there was no newcomer-old-timer network and the collectively created shared conceptual space was still being developed.

Eclipse Research Consultants (1996) developed a self-assessment technique, PICABUE, which would gauge potential partners' individual and collective commitment to the principles underpinning sustainability at the start of the project (Curwell et al, 1998). Eclipse embedded the principles into a simple mapping technique for ease of comparison which showed that not only were the different disciplines committed to different aspects and to greatly varying degrees, but that the partner averages increased and became more uniform between the aspects over time. This technique also allowed the 'common platform' to be established, which is a value representing the minimum amount of agreement between members. Represented as a percentage, it increased from 25% in 1996 to 45% in 2001.

New vs. Old Knowledge Production

One of the BEQUEST project deliverables was "an effective, multi-professional, international interactive networked community" to be mediated electronically over the Internet (BEQUEST 2001 p5). Pursued in this way, Cooper argues (2002 p117) that: "…the concerted action displayed some of the characteristics of a new approach to conducting global collaborative research that, in the UK at least, has very recently been given the very grand title of 'e-science'". Two defining characteristics of 'e-science' are the spatial distribution of those participating and the infrastructure, usually in the form of ICTs, which enable it. Its purpose is to achieve "world beating science through the effective use of the latest information technologies" by conducting cross-disciplinary research "at the intersection of many scientific disciplines", and that the resulting 'e-science' "will change the dynamic of the way science is undertaken" (Boyd, 2001, cited in Cooper 2002 p120).

E-science is one example of the pervasive trend towards the 'new' production of knowledge. Gibbons et al (1994) argue that the *way* in which knowledge is being produced is changing. They describe this knowledge (p 3-8) as being produced through 'mode 2 research' and some defining attributes include:

- Knowledge produced in the context of application (as opposed to problem solving using the codes of practice or a particular discipline);
- Trans-disciplinarity;
- Heterogeneity and organisational diversity (in terms of the skills and experiences brought to it);
- Social accountability and reflexivity;
- Quality control.

'New' knowledge may not show all of these characteristics, and it may not even be new: the description by Gibbons *et al* argue that innovation can occur through the reconfiguration of existing knowledge, so that it can be used in new contexts or by new users.

The expansion of the number, nature and range of communicative interactions between the different sites of knowledge production leads not only to more knowledge being produced but also to more knowledge of different kinds; not only of sharing of resources, but to their continuous configuration. Each new configuration becomes itself a potential source of new knowledge which in turn is transformed into the site of further possible configurations. The multiplication of the numbers and kinds of configurations are at the core of the diffusion process resulting from increasing density of communication...This process has been greatly aided by information technologies which not only speed up the rate of communication, but also create more new linkages. (ibid, p35). The development of communication linkages has played an important part in allowing this to occur, and this underlines the importance of the growth of the Internet and other computer-mediated communication and collaboration tools as enablers.

One of the most important conclusions Cooper (2002 p126) draws is that the BEQUEST concerted action has demonstrated that it is not necessary for all members to agree absolutely and at all times, within a research project team, for true progress to be made. What is important though, is that they are willing to negotiate openly about what they are trying to jointly achieve. The test of the validity of any group agreement will be in the reaction from other, wider stakeholders. With so little guidance on how to work effectively in inter-disciplinary groups, Cooper suggests (2002 p126) making explicit the amount of time and effort required to develop a shared perspective and that this should necessarily include trust and consensus building techniques and methods for identifying and resolving conflicts.

CASE STUDY 2: A MULTI-DISCIPLINARY UK UNIVERSITY RESEARCH PROJECT

Newell and Swan's (2000) case study is concerned with the development and maintenance of trust within a multi-disciplinary research team and the implications that this can have for inter-organisational working. The team was comprised of 4 project leaders and 4 researchers based at 3 geographically dispersed universities in the UK.

The Nature of Trust

It is generally agreed that trust is a necessary condition for co-operative behaviour among individuals, groups or organisations (Jones and George 1998) and that it facilitates the levels of communication necessary to generate learning and innovation in networked organisations (Dodgson 1993). Despite different definitions, the two central issues are that trust is about dealing with risk and uncertainty and that it is about accepting vulnerability. From their literature review, Newell and Swan (2000 p1295) conclude that a 3-fold trust typology exists:

1. Companion trust – based on goodwill judgements or personal friendships, it has an expectation of openness and honesty and although slow to develop, it is also the most resilient.
2. Competent trust – based on the perceptions of others' abilities to carry out necessary tasks, it can be driven by contextual cues – such as institution reputation. It develops more quickly, but is more fragile.
3. Commitment trust – stemming from contractual agreements between parties, the continuing existence of the contract in the absence of other trust forms makes it more resilient than competence trust.

Observer Findings

Through their in-depth analyses as invited outsider observers and team building facilitators, Newell and Swan found that the team started to break down very quickly after the project funding was received. Companion trust between two of the principal investigators (PIs) and perceptions of being able to enjoy working together led to the formation of the PI team. Temporary 'swift trust' (Meyerson et al 1996) developed based on competence cues taken from involvement on an expert panel and the quality and reputations of the universities to which each PI belonged. Crucially, in the rush to meet the proposal deadline the negotiation of the deliverables was omitted and in the light of little or no experience of working together and combined with epistemological differences of their disciplines, despite attempts to reach consensus, once work started, conflicts ensued.

The solution was to divide the project into semi-autonomous pieces which, through avoidance of conflict allowed their friendship to remain intact, but created centrifugal tensions which were later difficult to correct: this approach was agreed by everyone involved and it was often the case that the decisions made by the sub-groups would then be rejected by the other members. Newell and Swan concluded that had proper negotiations been held at the proposal stage, the group would have found that the idea would have shown itself to be unworkable. In the final phase, the research officers (ROs) got on board, but few attempts were made by the PIs to develop the informal, social coordination mechanisms and repeated changes to the project structure served to increase ambiguity and actually led to the PIs becoming less involved in the project. Disciplinary differences eroded competence trust between two of the RO s and this stared to undermine their companion trust and this eventually led to one of them leaving the project.

A Model of Trust

Newell and Swan argue that this work demonstrates how the three forms of trust interrelate and that ‘it is the way in which they worked together which provides the greatest understanding of the development of trust’. The PIs and ROs differed in terms of the commitment trust demonstrated and this appeared to affect the development of companion and competence trust. As a result of their observations, they make a number of propositions which could form the basis of a model:

1. *In a low commitment trust situation, competence and companion trust are reciprocally dependent, one reinforcing the other in the same direction*
   The spiral that results can be either positive or negative: Risk among the ROs was low if the network failed to deliver its original objectives and none would be held accountable - commitment trust was low. There is little to hold the individuals together and the downward spiral develops its own momentum, which can finish with total trust and maybe group breakdown. This occurred in the RO group - 2/4 left within the first 8 months.

2. *In a high commitment trust situation, competence and companion trust are held in mutual tension such that, as one decreases, the other increases to compensate*
   Commitment trust had been established via the funding body’s allocation of money which meant that, although there was high competence distrust, the same downward spiral didn’t occur in the way that it had for the ROs. Also, concerted efforts were made to remain friends and confrontation was avoided - through the development of federated sub-projects. Unlike the RO situation where competence distrust reinforced companion distrust, it acted to strengthen companion trust and, consequently, led to compromises and detracted from the benefits of interdependence. Newell and Swan (p1319) argue that this demonstrates why it is important to differentiate between different types of trust as they were affected differentially by the interactions which occurred.

3. *Putting in place formal integration mechanisms will not guarantee the development of the more informal integration mechanisms which underpin the emergence of at least companion and competence trust.*
   Here, the research team did not spend enough time on social integration. Newell and Swan go further by questioning the extent to which, if at all, multi-disciplinary teams actually produce more innovative and useful knowledge, especially given their epistemological and ontological

differences. Knights and Wilmott (1997) argue that the most common response to the pressures of inter-disciplinary research is 'mechanistic pooling' - each member takes a different 'slice' of the project and works with a minimum of communication with other members. This, they argue, is the most common response because "..no time is 'wasted' in confronting differences in theoretical perspective.." and "..each member is able to maximise publication output in journals that cater for their particular specialism.." (cited in Newell and Swan 2000 p1321). Here, the research team acted in a multi-disciplinary way.

4. *The greater the variety in epistemological and ontological perspectives within a research network, the more likely the output is to be a compromise, which is actually less creative and innovative than would have been achieved within a single discipline.*
   They conclude that any examples of really creative and interdisciplinary research are likely to be the exception rather than the rule and those multi-disciplinary approaches may inhibit creation and diffusion of innovative ideas.

INTER-DISCIPLINARY APPROACHES IN 3D2ND

Taking note of the above discussion, an attempt has been made to develop consensus amongst members of the project research team on the Salford 3D2nD modelling project. A workshop was conducted in February 2002 with the whole research team to start defining the theoretical and ontological approaches for a vision for the nD tool. An electronic voting tool was used during the workshop to ascertain any participant consensus. In order to define a vision, the workshop participants explored several existing visions governing 'the future of construction IT'.

Although aspects of the existing visions can be strategically placed within the context of this project, it was clear from the results that the majority of workshop participants – 88% - wanted to develop a new collective vision of their own. The preference for an approach based and focussed both on implementation and on a blue sky approach is the crux of the project as it will dictate the type of technology that would be used and the subsequent implementation issues of the chosen technology. The majority voted for a mixture of both aspects and the voting on the ratios of this showed that, of the two most popular responses, 28% wanted a 50:50 split, but that 27% favoured 20:80. The implementation timeframe for industry was most popularly agreed at 25 years, but the question provoked the least consensus of all, with a quarter of the group thinking that some sort of implementation should be possible within 3 years. It was generally concluded from the workshop that more work would need to be done with the group to develop consensus and a shared view around the vision, but that due to the nature of the grant it would be possible to develop a range of scenarios to accommodate all of these factors, each being comprised of varying degrees of applied and blue-sky/innovative technology. The scenarios would include technology that could be utilised readily and technology/visions that could be utilised in the future, encompassing multiple timescales and a vision that would be continuously and iteratively developed so that it would harness the future direction and application of technology.

DISCUSSION

The current situation in the 3D2nD project demonstrates a relatively low level of agreement on a number of the issues voted upon in the workshop. This would be expected given the multi-disciplinary nature of the group make-up and the lack of a unanimously agreed vision at this point in time. On the 'wheel of cognate disciplines' (Eclipse Research Consultants 1997), the nD group members' disciplines are represented at almost all stages around the circle, meaning that the groups furthest from each other may never agree and that, in fact, group decisions in general would be expected to be more polarized than was the case for BEQUEST. It would be quite fair to say that in the absence of a fully shared vision, it is human nature for individuals to try to steer a project towards their own goals and areas of expertise. However, it is also likely that with more formalised and specific goals in place, the research team will 'rally around' these. This was demonstrated by Cooper's (2002) case study of BEQUEST and the greater level of consensus demonstrated by the PICABUE assessment technique over the project's duration. It could be interesting and relevant to replicate this assessment exercise with the 3D2nD group, with some alteration to the concepts for consideration.

Newell and Swan (2000) highlighted a number of pitfalls which could be avoided through management, not only of the goals and tangible aspects, but also of the wider context and the inter-relationships of all those involved. Effective teamwork can only occur if there is a sense of ownership towards the project and its objectives by all the members of the research team. This does not mean that consensus on all aspects, by all members and at all times should be the only aim; rather than the process of striving to achieve these should help facilitate the development of factors which, in absence could bring down the project. The dominant theme in a set of case studies presented at the ISI seminar (Newell 2002) was the existence of trust, and although this may be the hardest aspect to control favourably, in the absence of consensus, if enough trust exists between members, collective goals and relationships are less likely to be lost and eroded.

Following from Coopers (2002 p118) distinction between inter- and multi-disciplinary work, it is difficult at this stage to determine which the nD project is. The project has not yet required any member to think and work beyond their discipline boundary; indeed the tool is currently envisioned as being a 'pool' for all information relating to building design and construction. The tool may take on an inter-disciplinary nature when applied to real world problems – if this is the remit – as it will be capable of more than the initial individual's inputs and should be able to cross the traditionally held discipline boundaries.

With the scarcity of previous research on how to best carry out multi-disciplinary work, an important by-product would be a paper on the management of the 3D2nD project and it mechanisms and contingencies for success and the processes by which these were achieved (or not). The encouragement of research councils to partake in research of this kind, but the ironic lack of knowledge on how to do this, highlights an area worthy of further consideration.

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